Canadian nuclear power
industry

Background Paper

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THE CANADIAN NUCLEAR POWER INDUSTRY

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Science and Technology Division

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THE NUCLEAR POWER INDUSTRY IN CANADA

Nuclear power, the production of electricity from uranium through nuclear fission, is by far the most prominent segment of the nuclear industry. The value of the electricity produced, $3.7 billion in Canada in 1992, far exceeds the value of any other product of the civilian nuclear industry. Power production employs many more people than any other sector, the capital investment is much greater, and nuclear power plants are much larger and more visible than uranium mining and processing facilities. They are also often located close to large population centres.

There is persistent public unease over nuclear power. There are a number of reasons for this. Increasing costs, particularly the escalating costs of building new power stations and refurbishing older stations, calls into question the assumption that nuclear power is cheaper than fossil-fuelled power. There is also a sense that some of the costs of nuclear power, including the costs of waste disposal and decommissioning, may not be fully accounted for. As well, the accidents at Three Mile Island and Chernobyl heightened anxiety over the safety and reliability of nuclear power systems. Reports of possible adverse effects on health from releases of low-level radiation from power plants also cause concern. Since, as yet, there is no decision on the ultimate disposal of nuclear wastes, there is also some sense that the industry is operating on borrowed time. Finally, for some, there is the inevitable association between nuclear power and nuclear weapons.

On the other hand, proponents of nuclear power contend that it can still produce electricity safely and economically and that high-level wastes can be safely disposed of, particularly since the volume of such wastes is relatively small. Proponents also argue that nuclear power is less damaging to the environment than fossil-fuelled power generation.

This paper provides an overview of some of the enormously complex issues surrounding nuclear power. It describes the Canadian nuclear power industry, addressing in particular its performance so far and future prospects.

EARLY CANADIAN NUCLEAR DEVELOPMENT

Over much of its history, Canada's CANDU reactor has been one of the most technically successful nuclear reactors. It may seem somewhat surprising that an intermediate industrial power like Canada should have succeeded where other countries have been considerably less successful. Two basic factors are primarily responsible: a core of early experience with nuclear technology in Canada and a decision to design a reactor tailored to Canadian circumstances.

The CANDU reactor has its origins in Canadian collaboration in the Allied program to develop the atomic bomb during the Second World War. In April 1944, a decision was reached by the Combined Policy Committee of the U.S., the U.K., and Canada that this country should build a heavy water reactor to produce plutonium from uranium.[1] Chalk River, now the location of AECL's Chalk River Laboratories, was selected as the site.

The first reactor, ZEEP (Zero Energy Experimental Pile), was to be used for research and to provide design information for the second, larger NRX (National Research Experimental) reactor. The initial purpose of the NRX reactor was to demonstrate the feasibility of making fissile material for atomic bombs in a heavy-water reactor.[2]

Although ZEEP was the first operational reactor in the world outside the United States, it did not start up until September 1945, too late to be of any significance to the war. In the years following, the emphasis of the work at Chalk River shifted to peaceful developments and the NRX reactor, which began operation in July 1947, gained a reputation as an outstanding research tool.

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(1) Wilfred Eggleston, *Canada's Nuclear Story*, Harrap Research Publications, London, 1965, p. 101.

(2) Gordon H.E. Sims, *A History of the Atomic Energy Control Board*, Minister of Supply and Services, Ottawa, 1981, p. 12-13.

In 1946, Canada passed the *Atomic Energy Control Act*, whose main purpose was to control and supervise the domestic development of nuclear energy and to enable Canada to participate in the international control of such energy.[3] The Act also established the Atomic Energy Control Board (AECB), which was initially intended to advise the government on policy[4] but which would later also assume the role of regulation of Canada's nuclear industry.

Atomic Energy of Canada Limited (AECL) was formed on 1 April 1952, to conduct research and development into the peaceful uses of nuclear science and technology. AECL took over responsibility for the operation of the Chalk River Laboratories,[5] which formed the core of the new corporation's activities.

Canada's first power reactor was the 22 MWe prototype NPD (Nuclear Power Demonstration) at Rolphton near Chalk River, which entered service in 1962. NPD was designed and built by a consortium of AECL, Ontario Hydro, and Canadian General Electric. The final NPD design incorporated all the basic characteristics of the CANDU design: natural uranium fuel, separate heavy water moderator and coolant, and a multi-channel horizontal pressure tube reactor core that allows refuelling with the reactor in operation. The name CANDU is derived from <u>Can</u>ada <u>D</u>euterium <u>U</u>ranium.[6]

The next stage of development was the 200 MWe station at Douglas Point on Lake Huron. Construction of Douglas Point was authorised in 1959 before the completion of its design and development phase and before the completion of NPD. Part of the justification for the construction of Douglas Point was to establish the real cost of a full-scale plant. By the time NPD began operating in 1962, Douglas Point was already under construction.[7]

Canada's first major commercial generation plant was at Pickering, east of Toronto on the shore of Lake Ontario. Plans for Pickering called for four units each of 500

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(3) *Ibid.*, p. 177.

(4) *Ibid.*, p. 205.

(5) Eggleston (1965), p. 148.

(6) Sims (1981), p. 116.

(7) *Ibid.*, p. 116-117.

MWe capacity; when it was completed in the early 1970s, Pickering was the largest nuclear generating station in the world.

Douglas Point was shut down in 1984 and NPD was shut down in 1987 but the first four units at Pickering continue to operate.

THE CANDU REACTOR

Conceptually, the production of electricity from uranium is straightforward. The heat produced by the controlled fission of uranium in the reactor core is used to generate steam; this drives turbines which, in turn, drive electric generators.

All the power reactors in Canada are Canadian-designed and built CANDU reactors. The CANDU differs in a number of important respects from virtually all other power reactors. Its principal distinguishing characteristics are: it uses natural rather than enriched uranium; it uses heavy rather than light (normal) water or graphite as the moderator; and the core is contained in pressure tubes rather than in the massive pressure vessel characteristic of pressurized light-water reactors. The core of the CANDU reactor is a large cylindrical vessel called the calandria, which contains the heavy water moderator. Several hundred "calandria tubes" pass from end to end of the vessel. Through the centre of each calandria tube passes a pressure tube containing fuel. Heavy water coolant, flowing through the pressure tubes at high temperature and pressure, transports the heat generated by fission to the steam generators.

The design of the reactor is particularly well adapted to Canadian conditions. The efficiency of heavy water as a moderator makes possible the use of natural rather than enriched uranium as the fuel. This avoids the difficult and expensive process of enrichment or, alternatively, dependence on foreign sources of enriched uranium. The CANDU also makes very efficient use of its fuel. A CANDU reactor uses about 160 kg of uranium to produce a megawatt-year of electricity.[8] A fossil-fuelled power plant requires 10,000 barrels of oil or

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(8) Alan Wyatt, *The Nuclear Challenge: Understanding the Debate*, The Book Press Limited, Toronto, 1978, p. 120.

2,100 tonnes of coal to produce the same amount of electricity.[9] The unit energy fuel costs for a CANDU reactor are less than for either light water reactors or for fossil-fuelled power generation.[10][11]

There are trade-offs, however. The capital cost of a CANDU reactor is higher than that of a light-water reactor of similar capacity. A significant portion of this cost is due to the initial inventory of heavy water. Heavy water is relatively rare, constituting only 0.015% of ordinary water, and is therefore expensive. In 1988, the cost of a kilogram of heavy water was estimated at approximately $550 and the initial inventory of heavy water was expected to contribute almost 14% of the projected capital cost of the Darlington power station.[12]

NUCLEAR POWER GENERATION IN CANADA

A. Background

Canada is one of the world's major producers of nuclear energy. In terms of total generation, it ranks sixth after the United States, France, the combined republics of the former U.S.S.R., Japan and West Germany.[13] Canada's relative dependence on nuclear power, however, is quite modest. In 1991, Canada generated 16.4% of its electricity generated at nuclear power stations, less than most western European countries, the United States, Japan, Taiwan, South Korea, and a number of other countries. By comparison, France, which has the world's most nuclear-intensive electricity generation, generated 73% (1991) of its electricity from nuclear power.[14]

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(9) *Fusion: Energy for the Future*, National Fusion Program, AECL Research, Chalk River, Ontario, 1991, p. 12.

(10) House of Commons Standing Committee on Energy, Mines and Resources, *Nuclear Energy: Unmasking the Mystery*, Queen's Printer for Canada, Ottawa, 1988, p. 138.

(11) Ontario Hydro, *Annual Report 1992*, p. 48.

(12) *Nuclear Energy: Unmasking the Mystery* (1988), p. 139.

(13) Atomic Energy of Canada Limited, *Nuclear Sector Focus 1993*, p. B-9.

(14) *Ibid.*, p. C-13, C-14.

In fact, Canada generates as much electricity from coal (17%) as it does from nuclear power. Hydro still accounts for 62% of Canada's electricity while oil and natural gas account for only 2.5 and 1.6% respectively.[15]

The national figures, however, do not depict the distribution of nuclear power within Canada. Of the 22 power reactors currently licensed to operate in Canada, 20 are located in Ontario, one in Quebec and one in New Brunswick. With this concentration of nuclear generating capacity, 50% of Ontario's electricity is generated by nuclear power; few countries exceed such a level. Although it has only one nuclear power station, New Brunswick still generates 35% of its electricity from nuclear power. Quebec, on the other hand, which relies almost exclusively on hydro power, generates only 3% of its electricity from its single nuclear power station.[16]

B. Performance

In recent years, Canada's nuclear industry has been the focus of a good deal of criticism. How well does it perform and how does it compare to the nuclear power industries of other countries?

A useful indicator of performance is "load factor." This is the ratio of electricity actually generated by a given reactor to the maximum that it could theoretically generate.[17] The load factor is important from an economic point of view because, as this increases, the unit cost of the electricity produced decreases.

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(15) *Ibid.*, p. E-6.

(16) *Ibid.*

(17) Load factors can give only a general indication of performance and strict comparisons will not always be valid. If a country has a mix of different types of generating capacity, nuclear power will generally be used to supply the base load and load factors will tend to be high. However, a country which relies predominantly on nuclear will need to use its nuclear generating capacity to follow load requirements; therefore, it will not always be used to full capacity and load factors will tend to be lower. For individual stations, annual load factors will be high if they have not had an outage to refuel during the measurement period. CANDU reactors are refuelled on power and therefore do not incur refuelling outages.

For much of their lives, Canada's CANDU reactors, as a whole, have performed well, while the performance of some individual reactors has been exceptional. In fact, Point Lepreau is one of the top three reactors in the world, achieving a load factor of 90.7% over its 10-year life.[18] Point Lepreau is not the only outstanding reactor; in terms of lifetime performance, six of the top 20 reactors out of over 350 around the world are Canadian CANDUs.[19]

Despite this outstanding performance by some reactors, the overall performance at all operating CANDUs is not as impressive. Table 1 lists load factors for countries with more than four reactors of 150 MWe gross capacity. In terms of the lifetime load factors, Canada ranks 8th with an average of 73.7%; however, in 1992, Canada ranked only 13th, with an average annual load factor of 65.3%.[20]

Much of the decline in performance can be attributed to aging at the oldest "A" stations; however, teething problems experienced at Darlington have also had an impact. Another general factor appears to have been insufficient maintenance at Ontario Hydro's nuclear plants. The decline in the performance of Bruce A, for example, has been attributed to reduced operations and maintenance budgets through the mid-eighties, which resulted in a growing backlog of maintenance work.[21] In 1993, the backlog of corrective maintenance work for Ontario Hydro's five nuclear stations amounted to 18,000 hours.[22]

Deterioration of the pressure tubes at Pickering A was one of the first major problems. Since then, there have been a number of other well-publicized problems, which are discussed in the following sections.

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(18) "1992 Annual Review of Load Factors," *Nuclear Engineering International*, April 1993, p. 24.

(19) *Nuclear Sector Focus 1993*, p. G-2.

(20) *Ibid.*, p. G-5.

(21) "The Cost of Not Doing Maintenance: a Cautionary Tale from Bruce A.," *Nuclear Engineering International*, March 1993, p. 15.

(22) Geoffrey Scotton, "Ontario Nuclear Plants Hit Safety Money Woes," *Financial Post*, 6 December 1993, p. 3.

Table 1
Performance by Country - Ranked by Lifetime Performance

Country	No. of Reactors	Annual Load Factor (%)	Lifetime Load (Factor %)	Capacity MWe
Hungary	4	87.4	84.3	1,840
Finland	4	89.3	83.8	2,400
Switzerland	5	84.1	81.5	3,109
Belgium	7	84.6	81.0	5,751
Czechoslovakia	8	76.3	77.5	3,542
Spain	9	82.9	74.7	7,388
South Korea	9	83.4	74.6	7,758
Canada	19	65.3	73.7	13,904
Germany	21	75.2	72.0	23,814
Sweden	12	76.0	70.6	10,422
Japan	42	72.3	68.9	33,399
Taiwan	6	76.3	67.2	5,144
France	55	62.8	63.1	59,104
Bulgaria	6	35.5	61.9	3,760
United States	109	68.5	61.5	106,743
United Kingdom	29	52.5	50.8	14,204
India	7	39.7	42.2	1,565

Source: Nuclear Engineering International - February 1993; AECL Nuclear Sector Focus 1993.

C. Pickering Nuclear Generating Station

One of the first major setbacks for the CANDU system occurred in 1983, when a pressure tube ruptured at Pickering 2. This incident led to the eventual retubing of all four Pickering A units. Retubing had been planned, but not as soon as proved necessary.

The CANDU is designed so that the pressure tubes in the core of the reactor can be replaced. In theory, this can effectively double the service life of the reactor. It was originally expected that the pressure tubes would last 15 to 20 years, but the pressure tube at Pickering 2 had been in service for only 11 years when it failed.(23)

(23) Geoff McCaffrey, AECL CANDU, personal communication.

Several factors contributed to the failure. During operation, the pressure tubes have a tendency to elongate. Spacers, called garter springs, which should have kept the pressure tubes centred inside the calandria tubes, had shifted out of position, allowing the pressure tube to sag and in some cases contact the cooler, outer calandria tube. The zirconium alloy used for the pressure tubes at Pickering 1 and 2 was also more susceptible to hydrogen absorption than expected. The hydrogen, which is produced by the effect of radiation on the heavy water coolant, formed hydrides, which migrated to the cooler contact points where they caused the alloy to become brittle, forming blisters and eventually cracks. Later CANDUS used a more hydride-resistant alloy for the pressure tubes and tighter-fitting garter springs with much less tendency to move. These later CANDUs are thus much less susceptible to pressure tube deterioration.

All four Pickering A units have been now retubed. The first, Pickering 2, took four years to retube. The last, Pickering 4, took only 19 months.(24) Retubing is expensive, not only because of the direct cost but because of the cost of buying replacement power. The direct cost of retubing Pickering 1 and 2, for example, was $402 million but the cost of replacement power for each unit was approximately $200,000 to $250,000 a day.(25)

Since retubing, the first three units to be retubed at Pickering A have performed well, with a combined load factor of over 80% in 1992. In fact, the performance of Units 2 and 3 was outstanding, at close to 90% load factor for both.(26)

D. Bruce Nuclear Generating Station

1. Retubing

After Pickering A, Bruce A, which started operation between 1977 and 1979, is the oldest multi-unit station in Ontario Hydro's complex of nuclear generating stations. Until recently it had been anticipated that the four stations at Bruce A would be the next to be retubed

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(24) *Ibid.*

(25) *Nuclear Energy: Unmasking the Mystery* (1988), p. 140.

(26) "1992 Annual Review of Load Factors," *Nuclear Engineering International* (1993), p. 20-21.

and refurbished. In principle, this would allow Bruce A to operate at high capacity until the end of its planned design life around 2017. Without retubing, operation of Bruce A would have to be phased out over the next decade.

As already noted, retubing Bruce A would represent a massive expenditure for Ontario Hydro at a time when it is already heavily in debt. The total cost has been estimated at about $3 billion, approximately $2 billion for repairs to the reactors and an additional $860 million to refurbish the station.[27] In March 1993, Ontario Hydro announced that it had deferred plans to retube the four units at the Bruce A Nuclear Generating Station, which would continue to be operated as long as safety permitted.[28]

A recent technical development may enable Ontario Hydro and other CANDU owners to avoid or delay the difficult choice between expensive repairs or early retirement of some CANDU reactors. The development is an improved version of a tool called a SLAR, (Spacer Location and Repositioning).[29] The SLAR is used to recentre the pressure tube inside the calandria tube and to reposition the garter springs. The SLAR can also measure the amount of sag and can use an ultrasonic probe to detect the location and severity of any blistering of the pressure tube.

The SLAR has already been used successfully at Bruce 4. If the tool continues to work as well as expected, it will extend the life of the pressure tubes, at a conservative estimate, by five to seven years. New Brunswick Power has already committed itself to a full-scale SLAR program, which is expected to postpone the scheduled retubing of its Point Lepreau reactor by ten years from 1998 to 2008.[30] By then, the pressure tubes will have been in service for 25 years.

2. Pressure Tube Frets

Another problem that has received considerable attention is a condition known as fretting. The station primarily affected is Bruce A. The cause is somewhat complex but the end

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(27) "Canada's Nuclear Watchdog..." *CP Newswire*, 1 May 1993.

(28) Ontario Hydro, *Annual Report 1992*, p. 11.

(29) "Revised SLAR Tool Puts Off Retubing," *Nuclear Engineering International*, April 1993. p. 10.

(30) Geoff McCaffrey, AECL CANDU, personal communication.

result is that vibration of the fuel bundle at the inlet end of the pressure tube wears grooves or "fret marks" in the pressure tube. The grooves are shallow (between 0.07 and 0.15 mm in Unit 1,[31] compared to a wall thickness of about 6 mm). By themselves, the fret marks do not pose much of a threat to the integrity of the pressure tubes. The concern arises because of the potential for the fret marks to act as stress points, which can encourage the formation of hydrides. In certain circumstances, hydrides can cause a condition known as "delayed hydride cracking," which could, potentially, cause a pressure tube to rupture.

The probability of having at one time all the specific conditions necessary to cause delayed hydride cracking appears to be low and, so far, delayed hydride cracking from fret marks has not been seen at any Bruce A reactor.[32] In addition, Ontario Hydro has carried out an analysis indicating that a crack would be detected by coolant leaking into the space between the pressure and calandria tube, thus allowing the reactor to be shut down before the pressure tube could rupture.[33] The AECB has decided that the risk is low enough to permit short-term operation of Bruce A[34] but has limited the number of additional operating cycles before ACEB approval will be required to continue operation.[35]

In November 1992, the AECB issued a six-month extension to Bruce A's operating licence, rather than renewing it for the normal two-year period. This was done to allow "time to resolve uncertainties regarding the long-term pressure tube integrity."[36] In May 1993, after reviewing the situation, the AECB granted a one-year operating licence to Bruce A.

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(31) Atomic Energy Control Board, *AECB Staff Annual Report of Bruce A NGS for the Year 1991*, Ottawa, November 1991, p. 11.

(32) Atomic Energy Control Board, *AECB Staff Annual Report on the Bruce A Nuclear Generating Station for the Year 1992*, Ottawa, September 1993, p. 11.

(33) *AECB Staff Annual Report of Bruce A NGS for the Year 1991*, p. 11.

(34) *AECB Staff Annual Report on the Bruce A Nuclear Generating Station for the Year 1992*, p. 15.

(35) *Ibid.*, p. 12.

(36) *Ibid.*, p. 13.

Some pressure tube fretting has also been found at Bruce B; however, the problem is less severe than at Bruce A. Pressure tubes at Bruce B were installed in such a way that stresses are very low and the pressure tubes are consequently less likely to develop cracks or fail.[37]

3. Shut Down System Design Flaw

Another serious problem at the Bruce Nuclear Generating Station came to light during an Ontario Hydro assessment of proposed changes to prevent further pressure tube fretting. A flaw was found in the analysis of a major loss-of-coolant accident. Under certain (highly improbable) conditions, the shut-down systems would not have a sufficient margin of safety if a major loss of coolant occurred while the reactors were operating at full power.[38] As a result of this discovery, all the Bruce reactors were derated to a maximum of 60% of full power, through the Bruce B reactors were subsequently allowed to increase to 80% of full power. The economic penalty for derating is very high; however, Ontario Hydro has already found solutions to the problem and is making modifications at Bruce which will be completed by the summer of 1994. The modifications will have the additional benefit of eliminating the major cause of fretting in the pressure tubes.

4. Steam Generators

The steam generators have also caused problems for Ontario Hydro both at Bruce A and to a lesser extent at Bruce B. Leaking steam generator tubes have resulted in a number of shutdowns of units at Bruce A. The cause of the leaks has been given as a combination of vibration-induced fatigue and stress corrosion cracking.[39] The problem was aggravated in one of the Unit 2 steam generators by a lead shielding blanket that had been accidentally left in the steam during an earlier shutdown.

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(37) Atomic Energy Control Board, *AECB Staff Annual Report on the Bruce B Nuclear Generating Station for the Year 1992*, Ottawa, September 1993, p. 12-13.

(38) Atomic Energy Control Board, *Annual Report 1992-93*, Minister of Supply and Services Canada, p. 9.

(39) *AECB Staff Annual Report on the Bruce A Nuclear Generating Station for the Year 1992*, p. 10.

The steam generators of the Bruce A units are undergoing an $80-million refurbishing which should be complete by the end of 1993. The program will restore Units 1, 3 and 4 steam generators to essentially new condition; however, the repairs to the Unit 2 generators, which had suffered greater deterioration, will not be as extensive.[40]

E. Darlington

Not all of Ontario Hydro's problems with its nuclear generating stations have been with its older units. The newest station of Ontario Hydro's complex of multi-unit nuclear generating stations is Darlington, located to the east of Toronto not far from Pickering.

1. Start-up Problems

During its start-up phase, Darlington has suffered from technical problems which have delayed its coming on full stream. The most serious of these problems have been damage to the fuel bundles and cracks in the main generator rotor shafts.

The fuel bundle damage, which was first discovered in early 1991 in Unit 2, was found to be caused by vibration of the fuel bundles inside the pressure tubes. The cause was traced to the main heat transport pumps in the heavy-water primary heat transport system. The pump impellers generated a 150-cycle per second pressure fluctuation, which could be amplified at certain points in the heat transport system causing excessive fuel bundle vibration.[41] This problem has been corrected by replacing the original pump impellers with impellers that shift the dominant frequency of the pressure fluctuation from 150 to 210 cycles per second.[42]

The main rotor generator shaft transfers mechanical power from the turbine to the rotor of the electric generator. The generator is not part of the nuclear reactor system but it is an essential part of the power station. The first five generator rotor shafts delivered at

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(40) Geoff McCaffrey, AECL CANDU, personal communication, 21 December 1993.

(41) "Cracked Fuel Halts Darlington Startup," *Nuclear Engineering International*, April 1992, p. 7.

(42) Atomic Energy Control Board, *AECB Staff Annual Report on the Darlington Nuclear Generating Station for the Year 1992*, Ottawa, September 1993, p. 13-14.

Darlington were found to be susceptible to developing cracks. The danger of this is that the cracks might grow and eventually cause a catastrophic failure of the rotor shaft.

Small cracks discovered in the generator shaft at Unit 2 caused lengthy shutdowns in both 1990 and 1991. In May 1992, a redesigned rotor shaft that eliminates the cracking problem was installed in Unit 2. The rotors in Units 1, 3 and 4 have been modified to allow the units to run, but will be replaced by the new design rotor. This was to be done in May 1993 for Unit 1 and in March and August 1994 for Units 3 and 4.(43)

As a result of its teething problems, power output from Darlington has been low. During its first three and a half years of operation, Unit 2 achieved a lifetime load factor of only 29.9% while Unit 1, between July 1992 and the end of June 1993, achieved a load factor of 56.8%.(44) Units 3 and 4, which started up in late 1992 and early 1993, have not been operating long enough to establish reliable load factors.

2. Costs

One of the major targets of criticism at Darlington has been its cost, which has far exceeded the original estimate and has helped to confirm the perception of the high cost of nuclear energy. Cost overruns are not unusual for large construction projects and, in the case of Darlington, many of the reasons for them were not directly related to the fact that it is a nuclear power plant.

Darlington was first ordered in 1973, although construction did not begin until about a decade later, between 1981 and 1985. Although earlier and lower figures have been used to gauge the cost escalation of Darlington, a realistic reference point is Ontario Hydro's estimate of $7.4 billion at the start of construction in 1981. This estimate was the first to include detailed engineering design and included allowances for inflation based on a 1988 project completion date.(45)

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(43) *Ibid.*, p. 14.

(44) "Load Factors to End June 1993," *Nuclear Engineering International*, November 1993, p. 19.

(45) Geoff McCaffrey, AECL CANDU, "Background-Darlington Costs," unpublished article.

The current estimate of $13.8 billion amounts to an increase of $6.8 billion or 86% over the 1981 estimate. The major contributing factor to the cost escalation has been delay in the construction schedule, which has added about $3.3 billion through additional interest charges on the money borrowed to finance construction. About half of the delays were due to construction problems. Other causes were initiatives to reduce capital expenditures, which delayed Units 3 and 4 by two years; more stringent AECB requirements; and an electrical workers' strike.

Financial policy changes by Ontario Hydro, including changes in the way that capital on multi-unit projects is brought into the rate base and the inclusion of the cost of nuclear training (previously charged against current operation), added a further $1.2 billion.

The two remaining contributing factors were design changes during construction, mostly due to changes in AECB regulations, which added about $0.9 billion, and a greater complexity of design and construction requirements than had been anticipated in the 1981 estimate which added a further $1 billion to the cost.

AECL

A. Introduction

Although Atomic Energy of Canada Limited (AECL) is not directly involved in the generation of nuclear power, it plays a major and essential role in the Canadian nuclear industry. AECL is the primary Canadian research and development agency in the field of nuclear energy. As such, it is responsible for the design, engineering, and marketing of CANDU reactors as well as providing engineering and scientific support services to CANDU owners. In addition, it conducts research and development in a wide range of basic and applied fields of science and technology.

AECL was incorporated as a federal Crown corporation in 1952 to carry out research and development in the peaceful uses of nuclear energy. AECL's stated mission is to maintain CANDU as a "long term, competitive electricity supply system" in support of a federal government policy of maintaining a domestic nuclear energy supply option.(46)

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(46) Atomic Energy of Canada Limited, *Corporate Plan and Budgets Summary 1992/93-1996/97*, Ottawa, April 1992, p. 1.

AECL has two main divisions, AECL CANDU and AECL Research, under the direction of a Corporate Office. The CANDU division is responsible for the design of CANDU plants, and both foreign and domestic marketing. It also provides engineering and project management services to its customers. The CANDU division is self-supporting and in fact operates at a profit that helps to underwrite R&D operation. The Research Division conducts research and development into the safety and efficiency of existing CANDU plants and improvements to the technology of future reactors.(47) The annual operating budget of the Research Division is about $300 million, of which about $160 million is provided by the federal government. Most of the rest comes from commercial operations and cost recovery from third parties. AECL's total workforce is made up of about 4,500 employees.

B. CANDU-Design and Marketing

1. Design

AECL's design activities are currently focused on the next generation of CANDU reactors: the 450 MWe CANDU-3 and the 900 MWe CANDU-9. AECL's top priority is the design of the CANDU-3 reactor, which is now more than 70% complete. The CANDU-9 is at a much earlier stage of development.

The 450 MWe CANDU-3 is significantly smaller than the standard AECL CANDU-6 (approximately 700 MWe). The CANDU-3 features a simplified modular design, which emphasizes a low capital cost, shorter construction times, high adaptability, high reliability and easy maintenance.(48)

This approach offers a number of advantages. AECL anticipates that the construction time of a CANDU-3 reactor will be three years. By comparison, the shortest construction time so far for a CANDU-6 has been about five years. A shorter construction time reduces the capital costs by minimizing the accumulation of interest charges. In principle, a

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(47) *Ibid.*

(48) Atomic Energy of Canada Limited, CANDU Operations, *Candu-3 Technical Outline*, Document Number 74-01010-TED-01 (Rev 9), September 1989, p. 1.

shorter lead time should also allow generation capacity to be better matched to demand. Another anticipated advantage of the CANDU-3 is that, because of its greater simplicity, countries with the basic technical abilities should be able to fabricate components for the CANDU-3 system.

The CANDU-3 design phase has been prolonged as a result of cutbacks at AECL and at present AECL does not have a firm date for completion, which may depend on customer commitment to CANDU-3.

Under the terms of a memorandum of understanding (MOU) signed with the Government of Saskatchewan in December 1992, AECL is relocating its design and engineering team and marketing office for the CANDU-3 to Saskatoon, Saskatchewan. The relocation entails placing a team of 115 employees in Saskatoon by December 1993 and increasing the team to its full complement of 140 by December 1994.(49)

The larger CANDU-9 is still at a very early stage of development. One of the factors driving its development is the difficulty of licensing new nuclear reactor sites. In this situation, maximum utilization of available sites tends to favour large capacity reactors. It should be remarked that the design of the 900 MWe units at Darlington, Ontario, was developed largely by Ontario Hydro and that the Darlington reactors are not CANDU-9 designs.

2. Marketing

a. Export Markets

Although the growth of nuclear power has slowed considerably, there are still a substantial number of nuclear reactors around the world either under construction or planned. Few orders have been placed for new reactors, however (only eight in 1991 and 1992).(50) Given the current market, AECL has done well in selling three CANDU reactors, all to South Korea, since 1990. The most recent sale of two CANDU-6 reactors to Korea Electric Power Co. (KEPCO) was announced in September 1992. This brings the total number of CANDUs sold to South Korea to four. Before these sales, the last sales of CANDU reactors were to Romania in the early 1980s.

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(49) Memorandum of Understanding between the Government of Saskatchewan and Atomic Energy of Canada Limited (AECL), 21 December 1992.

(50) *Nuclear Sector Focus 1993*, p. C-21.

At present, South Korea remains one of the best prospects for export sales. According to AECL, South Korean long-range plans call for three additional CANDU units beyond Wolsong 3 and 4. AECL anticipates that, after Wolsong 3 and 4, Korea will probably prefer the larger CANDU-9 reactors.[51]

As noted above, AECL sold five CANDUs to Romania between 1979 and 1985. Construction, which began at Cernavoda between 1980 and 1986, stalled when the project got into difficulties in the late 1980s. In 1991, the Canadian government made a decision to provide financing for a project management contract for Cernavoda 1 through the Canada Export Development Corporation.[52] The initiative should help to put the Romanian CANDU program back on track and it is now planned that Cernavoda will start supplying badly needed power by late 1994.[53]

In the longer term, the best prospects for export sales will probably be among the rapidly expanding economies of south-east Asia; however, there may also be some potential for sales in western Europe.[54]

b. Domestic Market

Prospects for the sale of CANDU reactors within Canada appear to be remote in the near future. Three provinces, Ontario, Quebec, and New Brunswick, already have nuclear facilities. Of the other provinces, only Saskatchewan has entertained the possibility of developing nuclear power.

After it was elected to power in September 1990, Ontario's NDP government placed a moratorium on the construction of new nuclear facilities in the province.[55] In reality the moratorium is mostly symbolic. Ontario now has a substantial surplus of electrical

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(51) Atomic Energy of Canada Limited, *Corporate Plan and Budgets Summary 1992/93-1996/97*, p. 3.

(52) *Ibid.*, p. 3.

(53) Atomic Energy of Canada Limited, *1991-1992 Annual Review*, Ottawa, 1992, p. 15.

(54) *Ibid.*, p. 17.

(55) Energy Mines and Resources, *1990 Canadian Minerals Yearbook*, Minister of Supply and Services, Ottawa, 1991, p. 67.8.

generating capacity. In December 1991, Ontario Hydro presented an updated version of its 25-year demand/supply plan, which now emphasizes demand-side management and non-utility generation and postpones the need for new generating facilities for the foreseeable future.(56) As far as Ontario is concerned, AECL CANDU's activities will be concentrated on the rehabilitation of Ontario Hydro's older "A" stations.

Quebec has only one operating nuclear power station, Gentilly 2, located near Trois Rivières. Quebec is committed to hydro generation and currently has more than sufficient hydro capacity to meet its expected needs. New Brunswick is the only other Canadian province that currently operates a nuclear generating station. AECL has had continuing discussions with New Brunswick Electric Power Corporation regarding a second nuclear power unit to be on-line by the end of the century but it is not yet clear if and when a firm project commitment might be made.(57)

In March 1992, a new Saskatchewan government decided not to proceed with the MOU reached between Saskatchewan Power Corporation and AECL under the previous government, which had offered some prospect of an expanded nuclear industry in Saskatchewan. In December 1992, the Saskatchewan government and AECL signed a new MOU, which, although it explicitly stated that the Government of Saskatchewan had made no pre-commitment to purchase a CANDU-3, did not rule out the possibility of its doing so.(58)

C. AECL Research

Most of AECL's nuclear-power-related research activities are carried out at its Chalk River Laboratories near Ottawa, Ontario, and at its Whiteshell Laboratories at Pinawa, in south eastern Manitoba.

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(56) Energy Mines and Resources, *1991 Canadian Minerals Yearbook*, Minister of Supply and Services, Ottawa, 1992, p. 50.10.

(57) Atomic Energy of Canada Limited, *Corporate Plan and Budgets Summary 1992/93-1996/97*, p. 3.

(58) *Memorandum of Understanding between the Government of Saskatchewan and Atomic Energy of Canada Limited (AECL)*, 21 December 1992.

AECL's research and development programs encompass a wide range of activities. A major portion of the corporation's efforts are dedicated to supporting CANDU operations. For example, AECL carries out research into means of reducing the probability of cracking and failure of pressure tubes. The AECL research program has also helped to determine the cause of the fuel bundle damage at Darlington. Another major area of activity is the development of radioactive waste disposal technologies, such as the concept of deep disposal of spent nuclear fuel in the Canadian Shield. Much of this work has been carried out at the Underground Research Laboratory near AECL's Whiteshell Laboratory in Pinawa, Manitoba.

Other areas of research include the environment and radiation biology. AECL also pursues the development of commercial technologies in both nuclear and non-nuclear fields.

D. Recent Developments

Like other sectors of the nuclear industry, AECL is being forced to streamline its operations. In January 1993, AECL announced that it would eliminate 250 positions from its research division in order to cut $15 million from its $300-million operating budget. This followed a federal government directive that AECL must become more self-sustaining.(59) The job cuts involved both Chalk River and Whiteshell and affected support staff rather than researchers. In an earlier move, the number of head office staff in Ottawa was reduced by almost two thirds, from 160 to 54.(60)

More recently, AECL has established a corporate task force to look into restructuring the corporation to increase its cost-effectiveness. The task force is to report its recommendations by the end of 1993 and the transition is to be completed during the first part of 1994.(61) Changes are necessary for AECL to meet its primary mission of supporting and advancing CANDU technology.

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(59) John Ibbitson, "Chalk River Feels Fiscal Pinch," *Ottawa Citizen*, 7 January 1993, p. A.1.

(60) "Atomic Energy Axing 250 Jobs," *Toronto Star*, 7 January 1993, p. 62.

(61) Tim Ruhnke, "Special AECL Task Team to Look at Restructuring," *The North Renfrew Times*, 29 September 1993, p. 6.

As a further cost-cutting measure, AECL has cancelled plans to build its new "Maple-X10" reactor, which would have produced radioisotopes for Nordion International and other customers.[62]

OUTLOOK

Energy is fundamental to Canada's standard of living and Canada has one of the highest per capita consumptions of energy of any country in the world. This is not the same as saying that our economy uses energy inefficiently. Our high per capita use of energy is partly due to the northern climate and large geographical area of the country as well as to the fact that much of Canada's industry is energy-intensive. Nuclear power makes an important contribution to Canada's energy supply mix. Ontario, in particular, with 50% of its electricity generated by nuclear power, is highly dependent on this source of power.

For Canada, nuclear power has a number of advantages. With more than sufficient reserves of uranium for its own requirements for the foreseeable future and a domestic nuclear fuel industry fully capable of supporting the CANDU system, nuclear power assures Canada of a secure domestic supply of energy. Rather than having to import fossil fuels, Canada exports uranium, which contributes to a positive balance of trade.

Nuclear technology is also one of the few high-technology sectors where Canada has world-class capabilities. Not only is Canada able to fulfil its own requirements for nuclear technology but exports of nuclear technology far exceed imports. In addition, there are other important spin-off industries, such as radio-isotope production, food irradiation technology, and radiotherapy equipment, in which Canada is a world leader.

On the other hand, nuclear power appears to be losing its historical cost advantage over coal-fired electricity generation. The costs of building new nuclear facilities continue to escalate as do the costs of repairing the older power stations. In addition there is persistent apprehension over the safety of nuclear power and the disposal of radioactive wastes, particularly spent fuel.

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(62) Tim Ruhnke, "AECL Stops Maple-X Project," *The North Renfrew Times*, 17 November 1993, p. 1.

There are also issues surrounding the environmental impacts of energy production. Often the debate centres on the relative merits of nuclear and coal-fired electricity generation. Concern over acid emissions and greenhouse gases would seem to give some advantage to nuclear power, although substantial gains have been made in reducing acid emissions from coal-fired generating stations. Advocates of sustainable development support a shift to energy conservation and renewable sources of energy. Undoubtedly there are significant gains to be made in energy conservation, but these will not occur overnight and, at some stage, further measures will not be justified by the diminishing returns. Moreover, renewable sources of energy, large hydro-electric developments for example, are themselves not without environmental impact. Even with greater reliance on renewable energy and conservation, conventional energy sources will still be required. The question is: what part will nuclear power play?

In the short term, there is realistically no alternative, particularly for Ontario, to the continued use of nuclear power. Since it has made the investment in nuclear facilities, for Ontario to turn to another form of electricity generation would be prohibitively costly.

The real issue is whether nuclear power will be gradually phased out over the long term or whether there will be a renewed commitment to further nuclear development as new generating capacity is required. If this happens, it will not be for some time. The current NDP government in Ontario has placed a moratorium on further nuclear development in the province and Ontario Hydro's current long-range plans do not foresee the need for new base load capacity in the near future.

The installation of new nuclear generating capacity elsewhere in Canada is uncertain. As discussed above, the only provinces that might consider building new nuclear facilities are Saskatchewan and New Brunswick. Low growth in electricity demand, however, means that neither province is likely to need new generating capacity until well into the next century.

Much will depend on whether the nuclear industry is able to renew confidence in the performance of its nuclear generating stations and whether it can produce electricity at a competitive cost. Although many of the technical problems affecting the older CANDU stations appear to have been resolved, it remains to be seen whether the industry can restore load factors

to the levels of the 1970s and early 1980s. The performance of the retubed units at Pickering A would suggest that this is possible. We must wait to see the performance of Darlington and whether it is now finally over the worst of its start-up difficulties.

AECL faces a special challenge. Although it will continue to play an important role in supporting the established CANDU systems both in Canada and abroad, it will almost certainly have to depend on export markets for new reactor sales. The CANDU-3, with its emphasis on adaptability, safety, reliability, short construction times, and ease of maintenance, should address many of the shortcomings of the current generation of reactors. Nonetheless, the CANDU will face stiff competition and, because of its relatively small capacity, will not be the reactor of choice in all situations; however, it may be attractive to utilities wishing to make smaller incremental additions to their base load capacities.

Canada's nuclear industry has survived for almost half a century but it is now at a critical juncture. Without sufficient commitment it is possible that Canada could eventually lose the core of expertise needed to support and develop the CANDU system. Once lost, this expertise would be next to impossible to recover. Although this would not preclude nuclear energy as an energy source in the future, it would limit our options and leave Canada dependent on other countries for nuclear technology.